GLOBAL EXPERIMENT: OPTIMIZATION OF NITROGEN FERTILIZATION RATE IN FRESHWATER TILAPIA PRODUCTION PONDS DURING COOL SEASON

Eighth Work Plan, Feeds and Fertilizers Research 1T (8FFR1T)
Final Report

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ABSTRACT

An experiment was conducted in twelve 200-m^2 earthen ponds at the Asian Institute of Technology, Thailand, for 91 days from 11 September to 11 December 1998. The experiment was designed to determine the optimal rate of nitrogen fertilization in cool season, to determine which of the nitrogen fertilization rates evaluated to produce Nile tilapia had the greatest profitability, and to develop a full-cost enterprise budget for the fertilization level that resulted in greatest profitability. Treatment ponds were fertilized with TSP at a rate of 8 kg ha^{-1} wk^{-1}, and with urea at 0, 10, 20, and 30 kg N ha^{-1} wk^{-1}, respectively. Sex-reversed male Nile tilapia were stocked at 1,000 kg ha^{-1} at a size of 23.1 to 25.5 g in all ponds (4.1 fish m^{-2}). Sodium bicarbonate was applied to all ponds weekly to attain and maintain the minimum alkalinity (75 mg l^{-1} as $CaCO_3$) based on weekly measurement of alkalinity in pond water. The experiment showed that greater nitrogen inputs resulted in better growth performance of Nile tilapia. Growth in the treatment without N inputs declined after the first fish sampling, which was earlier than the decline (around day 70) in treatments with N inputs. During the entire culture period, the estimated fish biomass was highest in the treatment with 30 kg N ha^{-1} wk^{-1}, intermediate in the treatments with 10 and 20 kg N ha^{-1} wk^{-1}, and lowest in the treatment without N inputs. The highest gross yield of Nile tilapia was obtained in the treatment with 30 kg N ha^{-1} wk^{-1} (1,938 ± 257 kg ha^{-1}, mean ± SE), intermediate in the treatments with 10 and 20 kg N ha^{-1} wk^{-1} (1,628 ± 190 and 1,755 ± 190 kg ha^{-1}, respectively), and the lowest in the treatment without N inputs (818 ± 109 kg ha^{-1}). The partial budget analysis indicated that the treatment with 30 kg N ha^{-1} wk^{-1} was most profitable. The full-cost enterprise budget showed that US$2.1 net return could be produced from a 200-m^2 pond in this treatment during a three-month culture period.

INTRODUCTION

Nile tilapia (*Oreochromis niloticus*) are commonly grown in semi-intensive culture using fertilizers to increase primary production and fish food (Boyd, 1976; Diana et al., 1991). There is voluminous literature on pond fertilization, documenting many conflicting and inconsistent results based on various types of fertilizer, rates of input, and methods and frequency of application (Coleman and Edwards, 1987). An efficient production system requires optimal use of nutrient inputs. Among a large number of nutrients required to stimulate phytoplankton growth, nitrogen, phosphorus, and occasionally carbon are the most common limiting nutrients in natural water and fish ponds (Lin et al., 1997). The research of the Pond Dynamics/Aquaculture Collaborative Research Support Program (PD/A CRSP) has addressed enhancement of primary productivity in ponds through additions of inorganic and organic fertilizers. However, the findings on optimal nitrogen, phosphorus, and carbon inputs required to improve fish yields at the PD/A CRSP sites appear to be inconsistent, and further research is needed. Higher nutrient inputs increased fish production at all PD/A CRSP sites, but optimal inputs of nitrogen, phosphorus, and carbon were not well defined (Lin et al., 1997).

Fertilization rates in PD/A CRSP experiments were much greater than rates reported for earlier pond fertilization research (Lin et al., 1997). In an often-cited series of fertilization experiments conducted in Malaysia, Hickling (1962) used less than 1.1 kg P and 1.1 kg N ha^{-1} wk^{-1}. In Israel, the standard fertilizer dose was 2.3 kg P and 6.5 kg N ha^{-1} wk^{-1} (Hepher, 1962a, b). The highest rates of phosphorus and nitrogen used in most experiments at Auburn University were 1.26 and 3 kg ha^{-1} wk^{-1}, respectively (Swingle, 1947; Boyd, 1976, 1990; Boyd and Sowles, 1978; Murad and Boyd, 1987). Rates in Europe seldom exceeded 1 kg ha^{-1} wk^{-1} for nitrogen and phosphorus (Mortimer, 1954). However, rates used in Malaysia, USA, Israel, and Europe gave low fish production. Also, in all of the studies cited above phosphorus was the most important limiting nutrient.

Therefore, the purposes of this study were to:

1) Determine the optimal rate of nitrogen fertilization (in the presence of adequate phosphorus and carbon) to obtain optimum primary productivity and optimum yields of Nile tilapia in freshwater production ponds;
2) Determine which of the nitrogen fertilization rates evaluated to produce Nile tilapia in freshwater production ponds had the greatest profitability;

3) Develop a full-cost enterprise budget for the fertilization level that results in greatest profitability.

METHODS AND MATERIALS

An experiment was conducted using a randomized complete block design in twelve 200-m^2 ponds at the Asian Institute of Technology, Thailand. The experiment involved the culture of Nile tilapia using four nitrogen fertilization rates.

All ponds were fertilized with triple superphosphate (TSP) at a rate of 8 kg ha^{-1} wk^{-1} and nitrogen (N), as urea, at 0, 10, 20 and 30 kg ha^{-1} wk^{-1}. All treatments were in triplicate. Initial pond fertilization took place two weeks prior to stocking of fish. Sodium bicarbonate was added weekly to attain and maintain minimum alkalinity (75 mg l^{-1} as $CaCO_3$) based on weekly measurement of alkalinity in pond water. Sex-reversed male Nile tilapia were stocked at 1,000 kg ha^{-1} at a size of 23.1 to 25.5 g in all ponds on 11 September 1998. The stocking density averaged 4.1 fish m^{-1} in all ponds.

Water depth in all ponds was maintained at 1 m throughout the experiment by adding water weekly to replace evaporation and seepage losses.

Most parameters of pond water quality were analyzed with column water samples taken from the center of each pond. Parameters of pond water quality, including total nitrogen (TN), total ammonium nitrogen (TAN), total phosphorus (TP), Secchi disk visibility, total alkalinity, and chlorophyll *a*, were analyzed at 1000 h during the second week (15 September 1998), midway (29 October 1998), and final week (8 December 1998) of the experiment using Standard Methods (APHA, 1980) modified by Egna et al. (1987). Dissolved oxygen (DO), pH, and temperature measurements were made on these three sampling dates at 0600, 1000, 1600, 1800, and 0600 h the following morning at 5-cm, 25-cm, 50-cm, and 75-cm depths in the water column. Total alkalinity and total hardness were determined weekly at 1000 h for calculating the amount of sodium bicarbonate required to maintain the minimum alkalinity defined as above.

During the experiment approximately 10% of the initial stock was seined, counted, and weighed en masse biweekly for each pond. All fish were harvested on 11 December 1998 after 91 days of culture. Daily weight gain (g $fish^{-1}$ d^{-1}), yield (kg $pond^{-1}$), and extrapolated yield (kg ha^{-1}) were calculated. Fish biomass on the sampling dates was calculated by the measured mean fish weight from sampling and the estimated number of fish surviving. It was assumed that surviving fish number decreased linearly from the beginning to the end of the experiment.

Data from the experiment were analyzed statistically by regression analysis and analysis of variance (ANOVA) using the SPSS 7.0 statistical software package. Differences were considered significant at an alpha level of 0.05. All means were given with ± 1 standard error (SE).

A partial budget analysis was conducted to determine which fertilization rate yielded the greatest profitability, and a full-cost enterprise budget was developed for the fertilization rate that yielded the greatest profitability (Shang, 1990). The economic analyses were based on the current local market prices expressed in US dollar (US$1 = 40 baht) in Thailand. Prices of urea and TSP were $0.200 and $0.325 kg^{-1}, respectively. Market value of Nile tilapia fingerlings around 30-g size was $1.50 kg^{-1}. To simplify the analyses the prices for stocked and harvested fingerlings were fixed to US$1.50 kg^{-1}. Total fixed cost in the full-cost enterprise budget was derived from a previous study (Engle and Skladany, 1992).

RESULTS

Growth performance of Nile tilapia was better with higher N inputs (Table 1; Figures 1, 2, and 3). Survival rates were not significantly different ($P > 0.05$) among all treatments. Differential growth of Nile tilapia among all treatments was observed at the first fish sampling (Figure 1). Growth in the treatment without N inputs ceased after the first fish sampling, while growth in the treatments with N inputs continued steadily through the experimental period (Figure 1). Final mean weight, mean daily weight gain, and gross and net fish yields were significantly higher ($P < 0.05$) in treatments with N inputs than those in the treatment without N inputs. However, there were no significant differences ($P > 0.05$) for those growth parameters among the treatments with N inputs (Table 1).

Table 1. Growth performance of Nile tilapia in ponds fertilized with different N rates (0, 10, 20, and 30 kg ha^{-1} wk^{-1}) in the 91-day experiment. Mean values with different superscript letters in the same row are significantly different ($P < 0.05$).

Performance	**Treatment**			
	0	*10*	*20*	*30*
Initial Biomass (kg $pond^{-1}$)	20.0 ± 0.0^a	20.0 ± 0.0^a	20.0 ± 0.0^a	20.0 ± 0.0^a
Initial Mean Weight (g $fish^{-1}$)	24.3 ± 0.6^a	23.4 ± 0.3^a	24.3 ± 0.4^a	24.7 ± 0.5^a
Final Biomass (kg $pond^{-1}$)	16.4 ± 2.2^a	32.6 ± 3.1^b	35.1 ± 3.8^b	38.8 ± 5.1^b
Final Mean Weight (g $fish^{-1}$)	28.2 ± 0.8^a	46.5 ± 1.6^b	53.9 ± 6.5^b	61.8 ± 8.0^b
Mean DWG (g $fish^{-1}$ d^{-1})	0.04 ± 0.01^a	0.25 ± 0.02^b	0.33 ± 0.07^b	0.41 ± 0.08^b
Net Fish Yield (kg $pond^{-1}$)	-3.6 ± 2.2^a	12.6 ± 3.1^b	15.1 ± 3.8^b	18.8 ± 5.1^b
Extrapolated Net Fish Yield (kg ha^{-1})	-181.7 ± 109.4^a	628.3 ± 155.3^b	755.0 ± 190.0^b	938.3 ± 256.7^b
Gross Fish Yield (kg $pond^{-1}$)	16.4 ± 2.2^a	32.6 ± 3.1^b	35.1 ± 3.8^b	38.8 ± 5.1^b
Extrapolated Gross Fish Yield (kg ha^{-1})	818.3 ± 109.4^a	$1,628.3 \pm 155.3^b$	$1,755.0 \pm 190.0^b$	$1,938.3 \pm 256.7^b$
Survival (%)	70.5 ± 9.0^a	81.9 ± 5.9^a	79.4 ± 2.6^a	77.3 ± 1.7^a

During the entire culture period, the estimated fish biomass was highest in the treatment with 30 kg N, intermediate in the treatments with 10 and 20 kg N, and lowest in the treatment without N inputs (Figure 2). The estimated fish biomass decreased after the first fish sampling (day 14) in the treatment without N inputs, resulting in negative net fish yields, while estimated fish biomass in the treatments with various N inputs kept increasing until the later part of the experimental period (around day 70) (Figure 2). Gross and net fish yields increased with increasing N inputs. The highest gross yield of Nile tilapia was obtained in the treatment with 30 kg N ha^{-1} wk^{-1} (1,938 ± 256 kg ha^{-1}), intermediate in the treatments with 10 and 20 kg N ha^{-1} wk^{-1} (1,628 ± 190 and 1,755 ± 190 kg ha^{-1}, respectively), and the lowest in the treatment without N inputs (818 ± 109 kg ha^{-1}) (Table 1; Figure 3). The relationship between net fish yield and N inputs (Figure 4) can be expressed as Y = 34.87 X + 12.00 ($R^2 = 0.60$, $P < 0.05$), which shows that net fish yield increases with increasing N inputs.

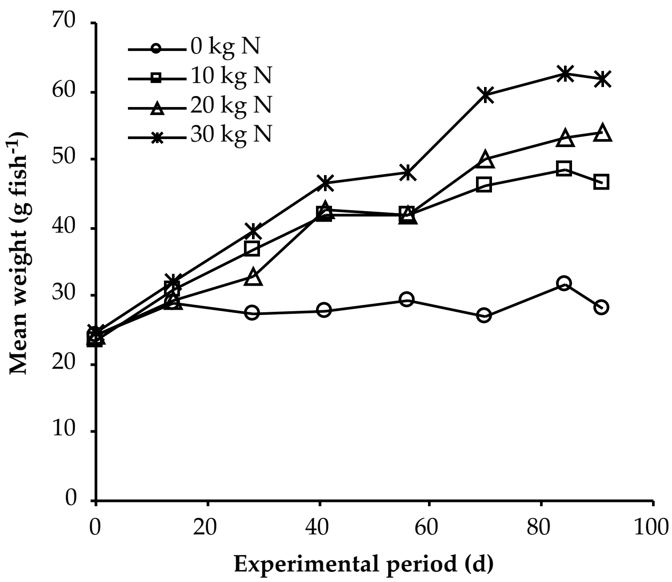

Figure 1. Growth of Nile tilapia in treatments with 0, 10, 20, and 30 kg N ha^{-1} wk^{-1} during the 91-day experiment.

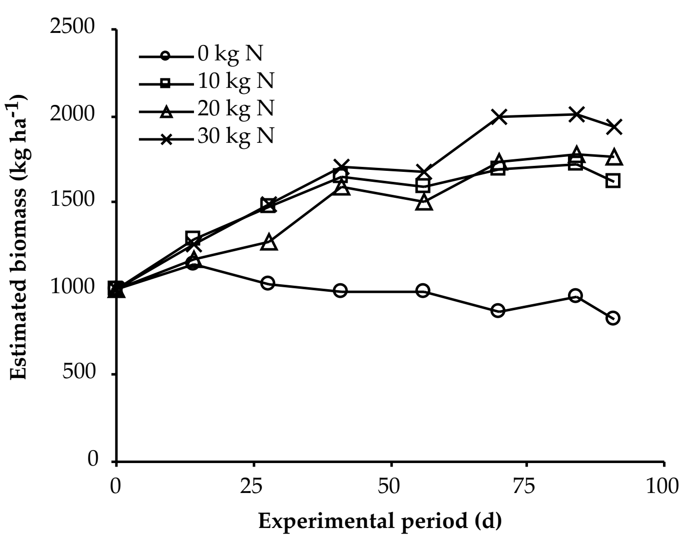

Figure 2. Estimated fish biomass in treatments with 0, 10, 20, and 30 kg N ha^{-1} wk^{-1} during the 91-day experiment.

Water quality parameters varied among treatments in the experiment (Table 2). There were no significant differences ($P > 0.05$) for all measured parameters except TN at the initial measurements. Water temperature and pH ranged from 26.0 to 36.8°C and 6.0 to 10.3, respectively, throughout the experimental period in all ponds. The DO concentration at dawn fluctuated over the entire culture period, but there were no significant differences ($P > 0.05$) among treatments. TN and TAN concentrations increased with increasing N inputs for all three measurements during the experiment. The final TN concentrations were significantly higher ($P < 0.05$) in treatments with N inputs than those in the treatment without N inputs. The final TAN concentrations in treatments with 20 and 30 kg N ha^{-1} wk^{-1} were significantly ($P < 0.05$) higher than that in the treatment without N inputs. However, there were no significant differences ($P > 0.05$) in final TAN concentrations between the treatments with 10 kg N ha^{-1} wk^{-1} and without N inputs. TP concentration was not significantly different ($P > 0.05$) among all treatments during the entire experimental period. To maintain the minimal alkalinity, the total amount of sodium bicarbonate added to ponds was 21.1 ± 0.9, 22.2 ± 1.9, 21.0 ± 3.3, and 19.6 ± 2.5 kg for the treatments with 0, 10, 20, and 30 kg N, respectively. Alkalinity fluctuated between 39 and 97 mg l^{-1} for all treatments during the culture period (Figure 5). There were no significant differences ($P > 0.05$) in alkalinity concentrations among all treatments during the entire culture

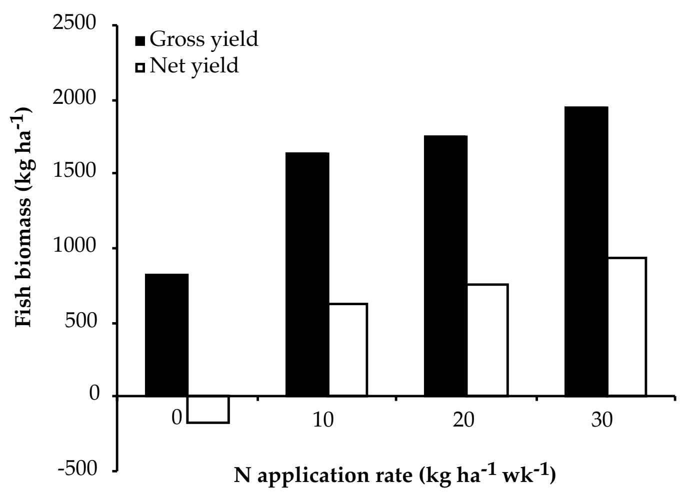

Figure 3. Gross and net fish yields in treatments with 0, 10, 20, and 30 kg N ha^{-1} wk^{-1} in the 91-day experiment.

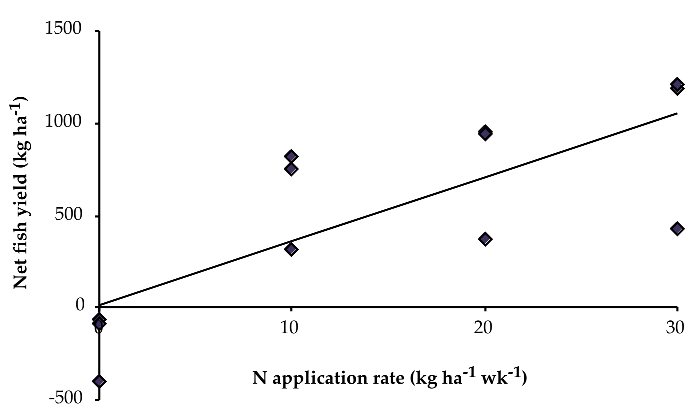

Figure 4. The relationship between net fish yield and nitrogen input rate in the 91-day experiment.

period. The concentrations of chlorophyll *a* were generally higher with increasing N inputs. The final concentrations of chlorophyll *a* were significantly higher ($P < 0.05$) in the treatment with N inputs than the treatment without N inputs. The treatment with 30 kg N ha^{-1} wk^{-1} had significantly higher ($P < 0.05$) final chlorophyll *a* concentration than the treatments with lower N inputs (10 and 20 kg N ha^{-1} wk^{-1}), but there were no significant differences ($P > 0.05$) between the latter two.

The partial budget analysis indicated that the treatment with 30 kg N ha^{-1} wk^{-1} was most profitable. However, the treatment with 30 kg N ha^{-1} wk^{-1} resulted in a high ratio of added income to added cost (Table 3). The full-cost enterprise budget showed that a $2.10 net return could be produced from a 200-m^2 pond in the treatment with 30 kg N ha^{-1} wk^{-1} during a 3-month culture period (Table 4).

DISCUSSION

The addition of nitrogen fertilizer significantly increased Nile tilapia yields. Greater N inputs resulted in higher phytoplankton productivity, giving higher tilapia yields. The nitrogen inputs at rates of 10, 20, and 30 kg ha^{-1} wk^{-1} in ponds fertilized with 8 kg P ha^{-1} wk^{-1} brought the N:P ratio to 1.25:1, 2.5:1, and 3.75:1, respectively. The best fish growth performance was achieved in the treatment with the highest N input and N:P ratio. The result is consistent with that of a similar experiment done in the warm season (Lin et al., 1999). This finding confirms the previous results of CRSP experiments which showed optimal rates of 28 kg N ha^{-1} wk^{-1} and 7 kg P ha^{-1} wk^{-1} giving a 4:1 N:P ratio (Knud-Hansen et al., 1991; Lin et al., 1997). Nile tilapia ceased to grow starting around the day 70 in all treatments with various N inputs, indicating that the pond

Table 2. Mean values of water quality parameters measured at the initial, midway, and final week in ponds fertilized with different N rates (0, 10, 20, and 30 kg ha^{-1} wk^{-1}) in the 91-day experiment. Mean values with different superscript letters in the same row are significantly different ($P < 0.05$).

Parameter	Treatment			
	0	10	20	30
DO AT DAWN (mg l^{-1})				
Initial	2.53 ± 0.29^{a}	2.05 ± 0.26^{a}	2.60 ± 0.16^{a}	2.72 ± 0.21^{a}
Midway	3.55 ± 0.19^{a}	2.08 ± 0.44^{a}	2.73 ± 0.34^{a}	1.57 ± 0.46^{a}
Final	4.48 ± 0.09^{a}	3.07 ± 0.24^{a}	4.12 ± 0.48^{a}	4.42 ± 0.72^{a}
pH				
Initial	7.1–9.6	7.1–10.3	7.2–9.9	7.0–10.3
Midway	6.0–9.1	6.2–9.0	6.1–9.5	6.0–9.8
Final	6.6–9.9	6.2–10.0	6.5–10.3	6.6–10.2
TOTAL NITROGEN (mg l^{-1})				
Initial	1.01 ± 0.05^{a}	1.37 ± 0.18^{ab}	1.70 ± 0.04^{bc}	2.19 ± 0.29^{c}
Midway	1.95 ± 0.32^{a}	3.40 ± 0.53^{ab}	3.90 ± 0.36^{bc}	5.30 ± 0.59^{c}
Final	2.01 ± 0.22^{a}	4.64 ± 1.40^{b}	6.75 ± 0.16^{bc}	8.98 ± 0.54^{c}
TAN (mg l^{-1})				
Initial	0.42 ± 0.37^{a}	0.49 ± 0.49^{a}	0.91 ± 0.24^{a}	0.75 ± 0.75^{a}
Midway	0.13 ± 0.13^{a}	0.26 ± 0.02^{a}	0.74 ± 0.22^{a}	0.71 ± 0.71^{a}
Final	0.36 ± 0.15^{a}	0.65 ± 0.36^{ab}	2.20 ± 0.23^{b}	2.37 ± 0.55^{b}
TOTAL PHOSPHORUS (mg l^{-1})				
Initial	0.22 ± 0.01^{a}	0.31 ± 0.04^{a}	0.24 ± 0.02^{a}	0.31 ± 0.04^{a}
Midway	0.21 ± 0.02^{a}	0.37 ± 0.07^{a}	0.35 ± 0.07^{a}	0.44 ± 0.10^{a}
Final	0.34 ± 0.03^{a}	0.55 ± 0.15^{a}	0.45 ± 0.05^{a}	0.75 ± 0.10^{a}
TOTAL ALKALINITY (mg l^{-1} as $CaCO_3$)				
Initial	54 ± 5.3^{a}	51 ± 3.3^{a}	52 ± 5.0^{a}	53 ± 4.1^{a}
Midway	53 ± 1.8^{a}	59 ± 7.3^{a}	55 ± 9.6^{a}	54 ± 3.1^{a}
Final	82 ± 5.0^{a}	72 ± 8.1^{a}	74 ± 7.0^{a}	97 ± 18.4^{a}
CHLOROPHYLL *A* (mg m^{-3})				
Initial	30 ± 4.6^{a}	54 ± 11.0^{a}	34 ± 11.5^{a}	56 ± 10.0^{a}
Midway	16 ± 2.6^{a}	49 ± 11.2^{a}	52 ± 18.0^{a}	108 ± 39.4^{a}
Final	19 ± 3.8^{a}	51 ± 14.9^{b}	61 ± 9.0^{b}	158 ± 54.4^{c}

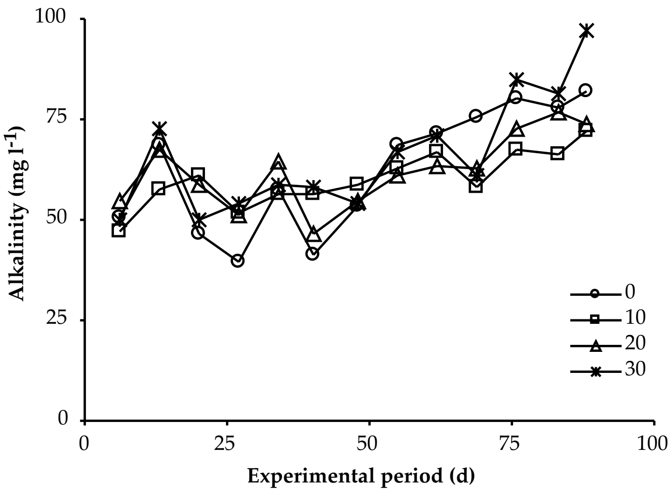

Figure 5. Change in alkalinity concentration in the treatment with 0, 10, 20, and 30 kg N ha^{-1} wk^{-1} over the 91-day experiment.

carrying capacity was near 2,000 kg ha^{-1} in the cool season, compared with 2,000 to 2,500 kg ha^{-1} in the warm season. With chemical fertilization alone, maximum fish production is about 15 kg ha^{-1} d^{-1} (Boyd, 1990), which is similar to the highest net fish yield (15.3 kg ha^{-1} d^{-1}) achieved in this 91-day experiment. However, the net fish yield would reach 19.9 kg ha^{-1} d^{-1} and much higher profit could be produced if tilapia had been harvested before growth ceased around the day 70, suggesting the importance of timing for fish harvest in optimization of pond production systems.

The optimal N and P input rates determined in PD/A CRSP experiments are much higher than those used in most previous pond experiments, ranging from 1.0 to 6.5 kg N and 1.0 to 2.3 kg P ha^{-1} wk^{-1} (Swingle, 1947; Mortimer, 1954; Hickling, 1962; Hepher, 1962a, b; Boyd, 1976, 1990; Boyd and Sowles, 1978; Murad and Boyd, 1987). The annual fish yields in those studies were generally below 1,000 kg ha^{-1}. In addition to higher fertilizer inputs, the fish stocking rates were also much higher in most PD/A CRSP experiments (10,000 to 20,000

Table 3. Partial budget analysis for Nile tilapia cultured in ponds fertilized with different N rates (0, 10, 20, and 30 kg ha^{-1} wk^{-1}) in the 91-day experiment (budget items in US\$ $pond^{-1}$).

Item	Treatment			
	0	10	20	30
Income (Selling Fish)	24.60	54.45	52.65	58.20
Added Income (A)	----	29.85	28.05	33.60
Cost for Urea	0	1.30	2.60	3.90
Added Cost from Urea (B1)	----	1.30	2.60	3.90
Cost for $NaHCO_3$	16.35	17.20	16.28	15.20
Added Cost from $NaHCO_3$ (B2)	----	0.85	-0.07	-1.15
Ratio of Added Income to Added Cost	----	13.9	11.1	12.2
Profit (A - B1 - B2)	----	27.70	25.52	30.85

Table 4. A full-cost enterprise budget for Nile tilapia cultured in ponds fertilized with 30 kg N ha^{-1} wk^{-1} in the 91-day experiment.

Item	Unit	Price (US\$)	Quantity (kg $pond^{-1}$)	Value (\$ $pond^{-1}$)
GROSS REVENUE (A)				
Harvested Tilapia	kg	1.50	38.8	58.20
COST				
Variable Cost				
Fingerlings	kg	1.50	20.0	30.00
Urea	kg	0.20	19.6	3.90
TSP	kg	0.33	12.0	3.90
$NaHCO_3$	kg	0.78	19.6	15.20
Interest on Operating Capital	yr	12%	0.25	1.60
Total Variable Cost				54.60
Fixed Cost				
Pond Depreciation and Equipment	ha*yr	133.75	0.02*0.25	0.68
Interest on Fixed Capital	yr	12%	0.25	0.80
Total Fixed Cost				1.48
TOTAL COST (B)				56.08
NET RETURNS (A - B)				2.13
BREAK-EVEN PRICE	kg	1.45		

fish ha^{-1}) with extrapolated annual fish yields of 3,000 to 5,000 kg ha^{-1} (Lin et al., 1997). The highest extrapolated net yield obtained in the present study is around 3,750 kg ha^{-1} yr^{-1} and could have reached 5,000 kg ha^{-1} yr^{-1}, if fish had been harvested around the day 70. These yields are lower than those (5,500 and 7,000 kg ha^{-1} yr^{-1}, respectively) obtained in the warm season.

With the development of Nile tilapia cage culture in rivers in northeast Thailand, there are strong demands for large fingerlings (30 to 50 g) to stock cages. Small-scale farmers nurse Nile tilapia fry to such sizes and sell them at around \$1.50 kg^{-1}, which is much higher than the price of marketable adult Nile tilapia. Farmers commonly nurse fry in fertilized ponds supplemented with artificial feed. In the present study, however, Nile tilapia were nursed at a very high density in ponds with fertilizer only, resulting in high yields. This study implies that moving fish from a high to low density when fish growth ceases or pond carrying capacity is reached could be a good strategy. Results of the present study may provide small-scale farmers with a technically and economically effective strategy to optimize resource utilization and maximize profits.

Anticipated Benefits

This is the first in a series of experiments to determine optimal rates of nitrogen, phosphorus, and carbon additions to ponds for fish production. Results of these trials will determine N, P, and C application rates to obtain fish yields with the greatest profit. Development of a full-cost enterprise budget for the fertilization rate that results in the greatest profitability will assist host-country and international economists and planners in their evaluation of fish culture systems. Identification of optimal nutrient application rates would reduce the environmental impact of pond effluents.

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